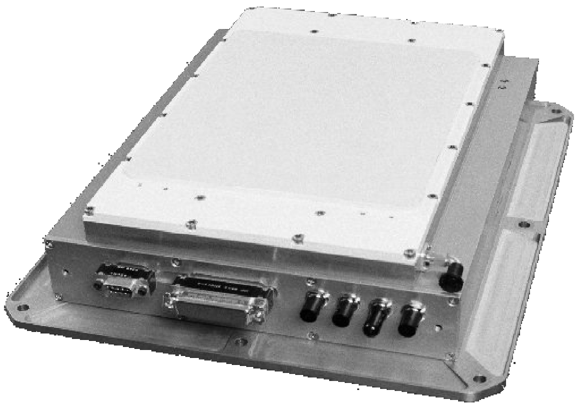

# Section 23b

## XPAA Technology Validation



***. . . Kenneth Perko***

*EO-1 XPAA Lead, Microwave Systems Branch*

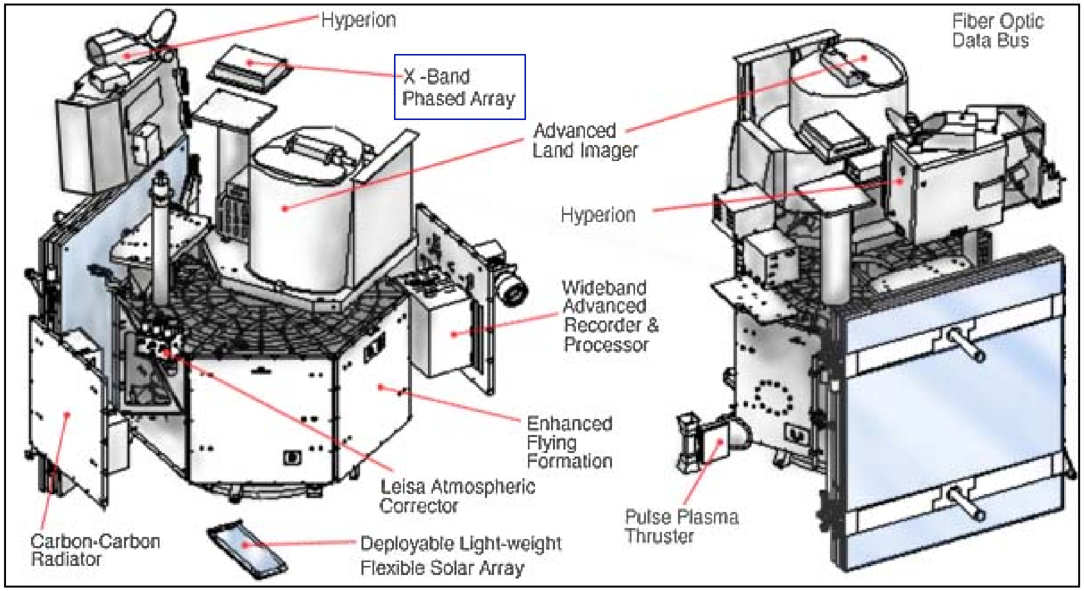
# Topics of Discussion

- *Introduction – Phased Array Developments at Boeing*
- *Technology Description – XPAA Development for EO-1*
- *Technology Validation*
- *Technology Transfer and Infusion Opportunities*
- *Lessons Learned*
- *Summary/conclusions*

# Technology Validation Objectives



- ***Demonstrate that phased array technology has benefits to small spacecraft architecture and operations***
- ***Demonstrate that phased array technology is mature and reliable for use in space environment***
- ***Minimize impact on phased array complexity / cost***
- ***Constrain impacts to spacecraft system***



# X-Band Validation Plan & Methods



| Validation Plan | Method |
|---|---|
| ◆ ***6.1 Validate the communications link error performance of this type of phased array.*** | ➢ ***Review downlink spectrum and compare to pre-flight. Evaluate burst-error performance of link to look for phased array specific effects.*** |
| ◆ ***6.2 Validate the antenna pattern and scan performance of the phased array.*** | ➢ ***Capture downlink power over entire pass and compare variations to prediction based on pre-flight data.***<br>➢ ***Fix beam pointing and capture downlink "antenna pattern."*** |
| ◆ ***6.3 Validate the performance and reliability of the software and controller of the array in the space environment.*** | ➢ ***Verify 6.2, monitor box pointing telemetry. Monitor and trend box telemetry.*** |

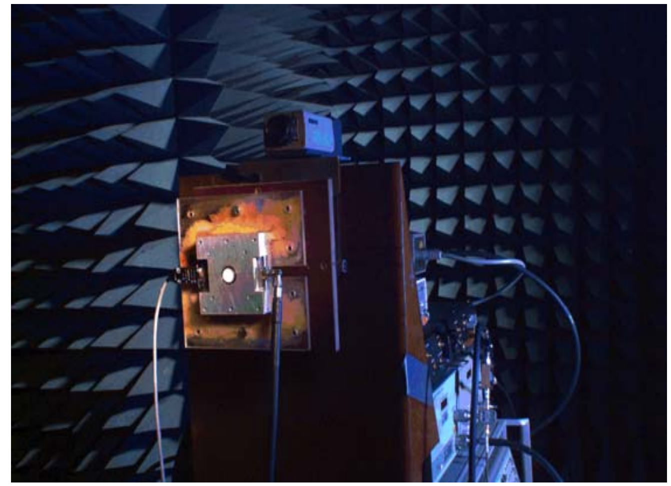
# Validation Data Sources



- ***Pre-Flight Data***
  - ***Boeing Acceptance Data***
    - *Telemetry, Antenna Patterns, NF Scans of Flight Unit*
  - ***Tests of Engineering Models***
    - *Elements and Sub-arrays for Communications Performance*
  - ***GSFC I&T Data***
    - *Telemetry, NF Scans, Reed-Solomon Performance*
- ***Flight Data***
  - ***Reed-Solomon Performance***
  - ***S/C Telemetry***
  - ***Ground Station Measurements***
    - *Received Power Contours, Antenna Patterns*

# Engineering Model Testing at GRC

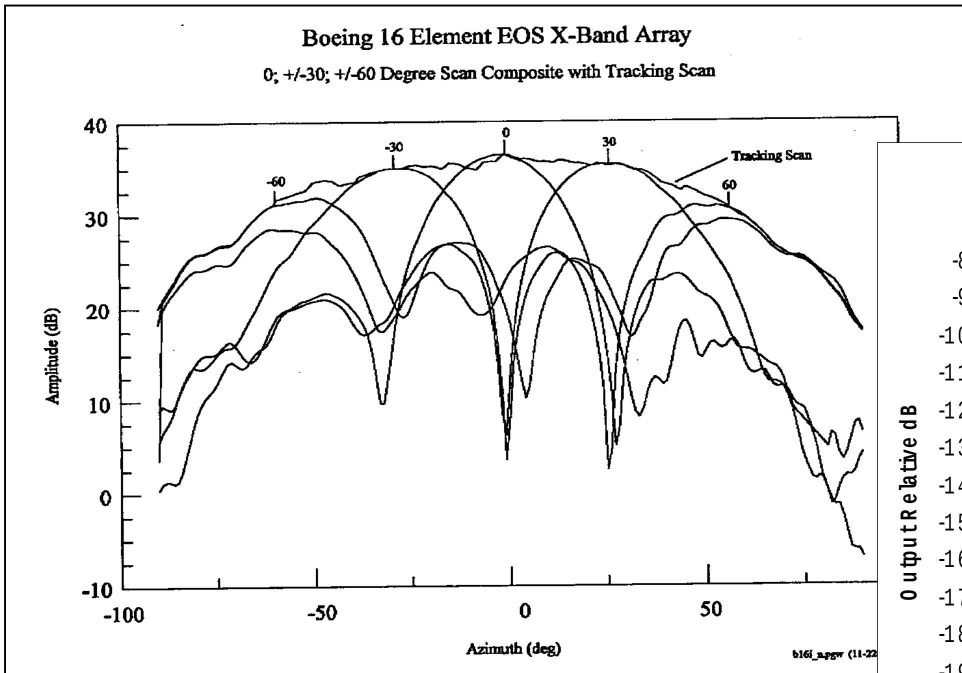
- ***Individual elements and a 16-element sub-array were tested for output power, efficiency, and ability to transmit high-rate data.***
- ***Tests of high-rate communication performance (static and dynamic pointing) showed that electronic scanning had no significant impact.***

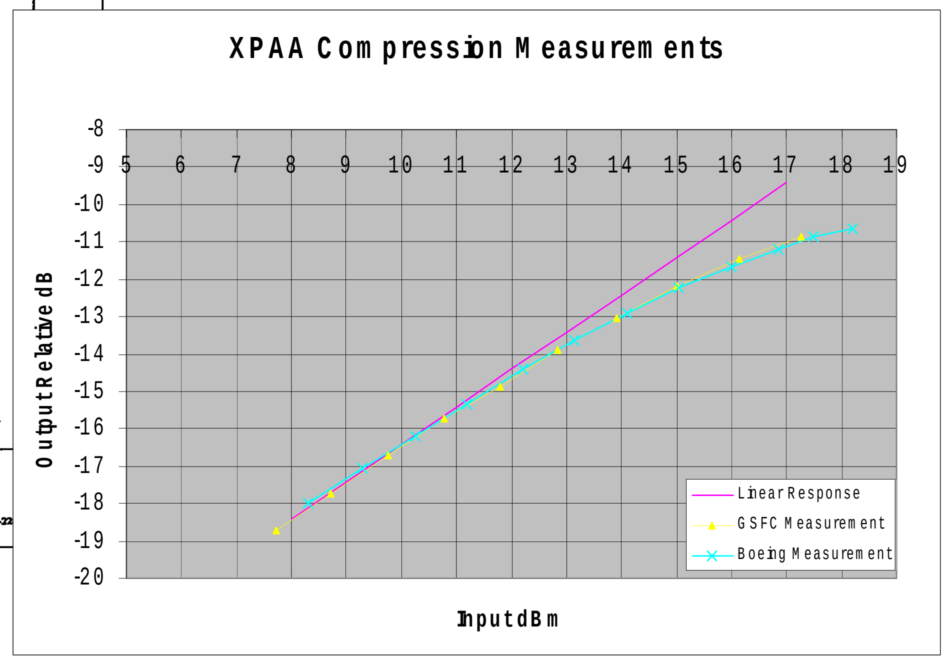


# Pre-Flight Ground Validation



- ***Establish baseline performance using engineering models, flight unit acceptance tests and S/C I&T data***

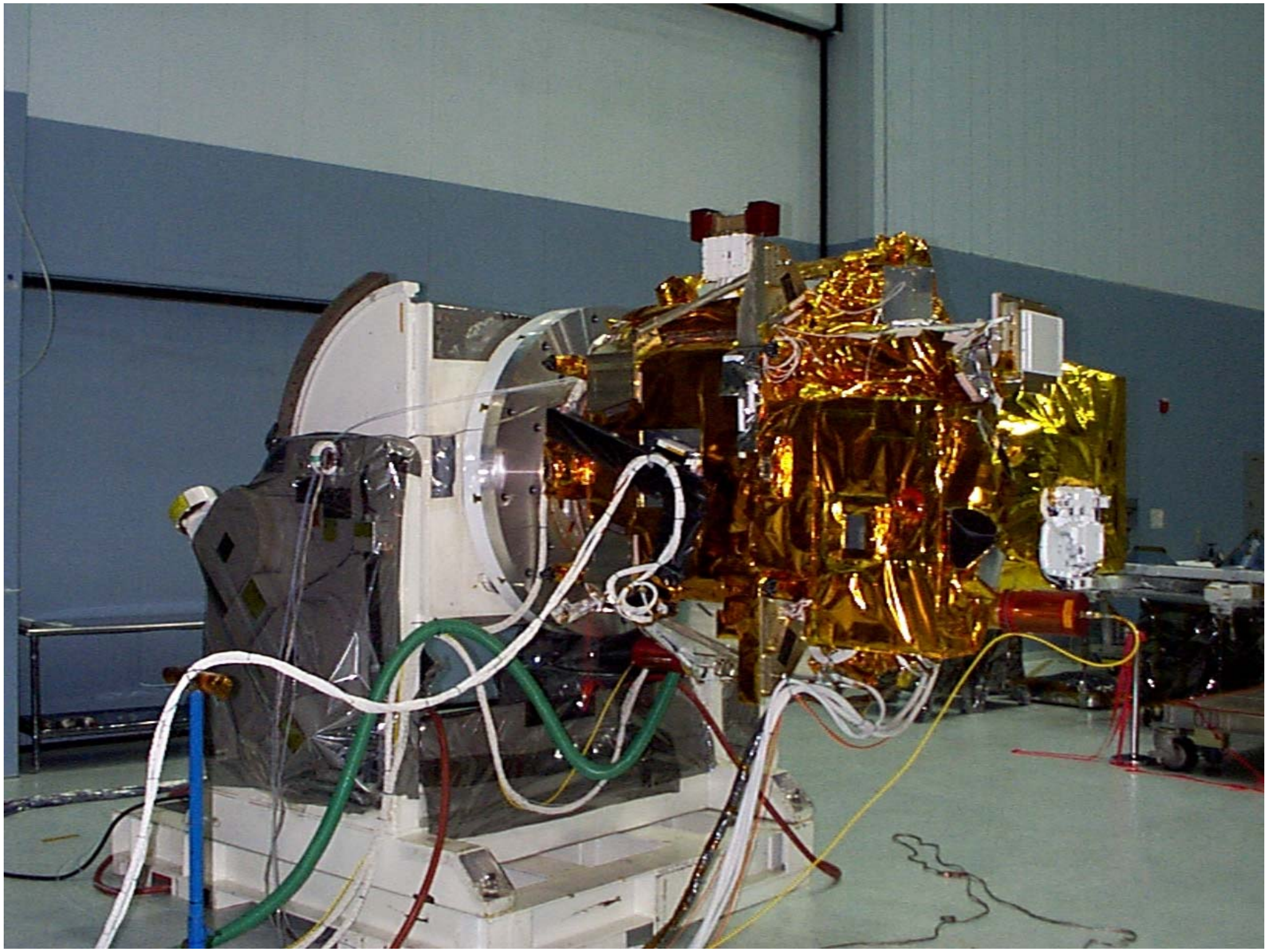


Earth Observing-1

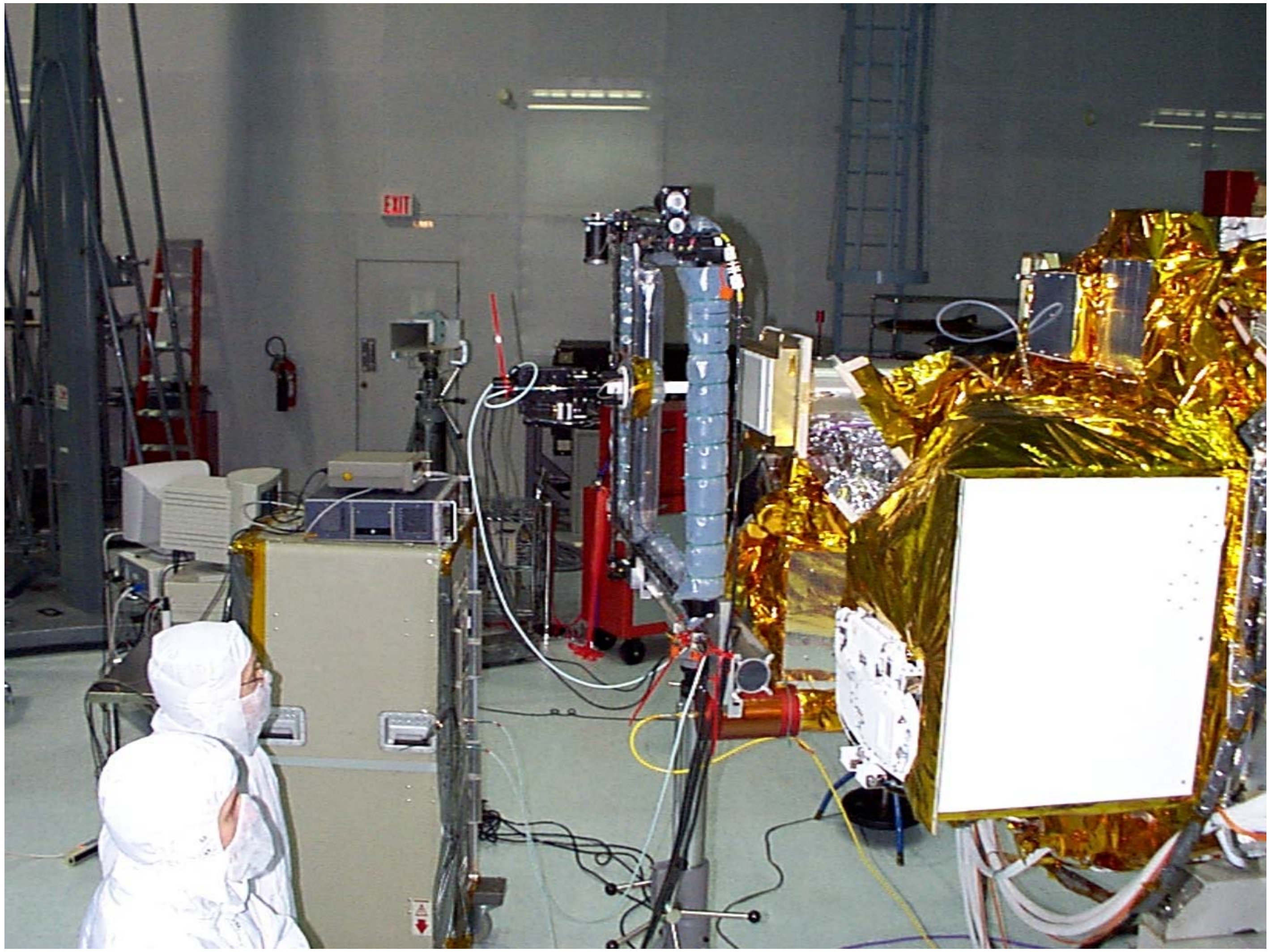
# XPAA on EO-1 During Clean Room Testing at GSFC

Mission Technology Forum



# XPAA Near Field Scan

*NF Scanner in Position in Front of the XPAA During Clean Room Tests at GSFC*



# XPAA Pattern Comparison



## Comparison of NF3 Cut and Boeing Anechoic Chamber Cut for XPAA Pointed to Theta=00, Phi=000

*Black = Boeing Data, Red = NF3 Data*

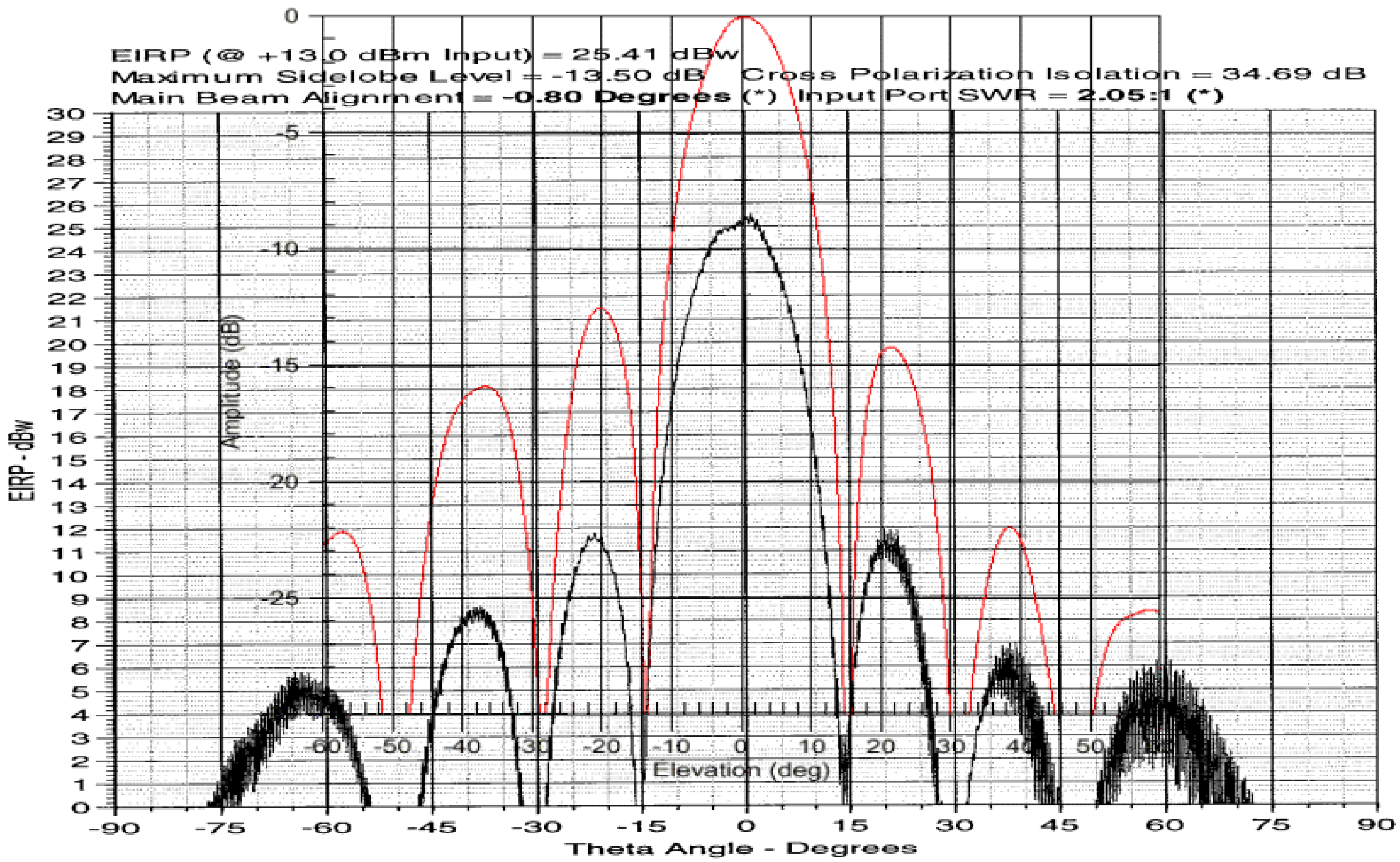
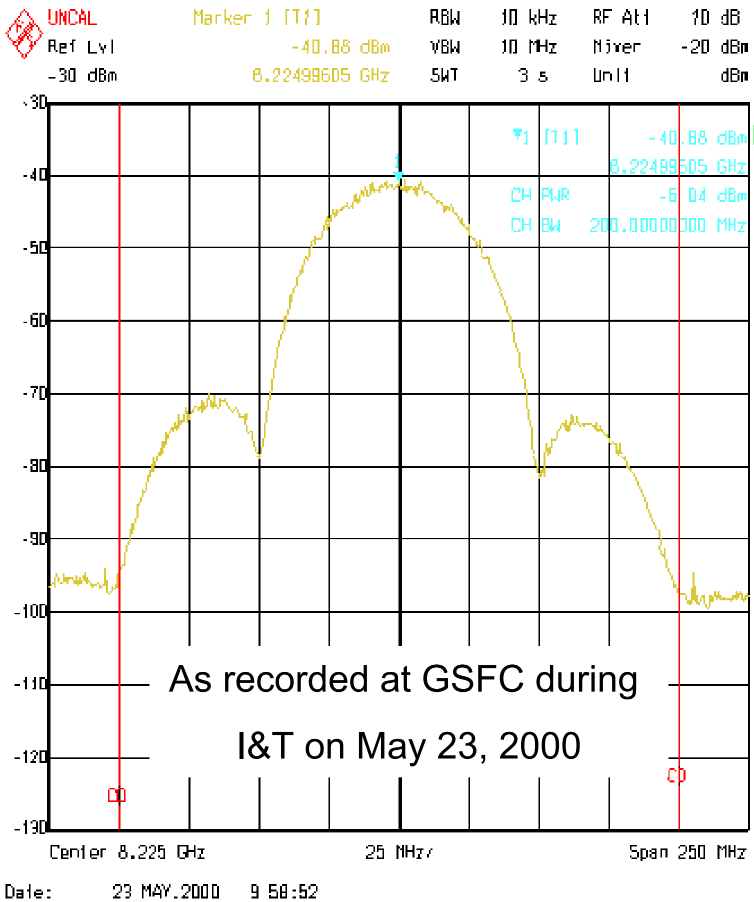


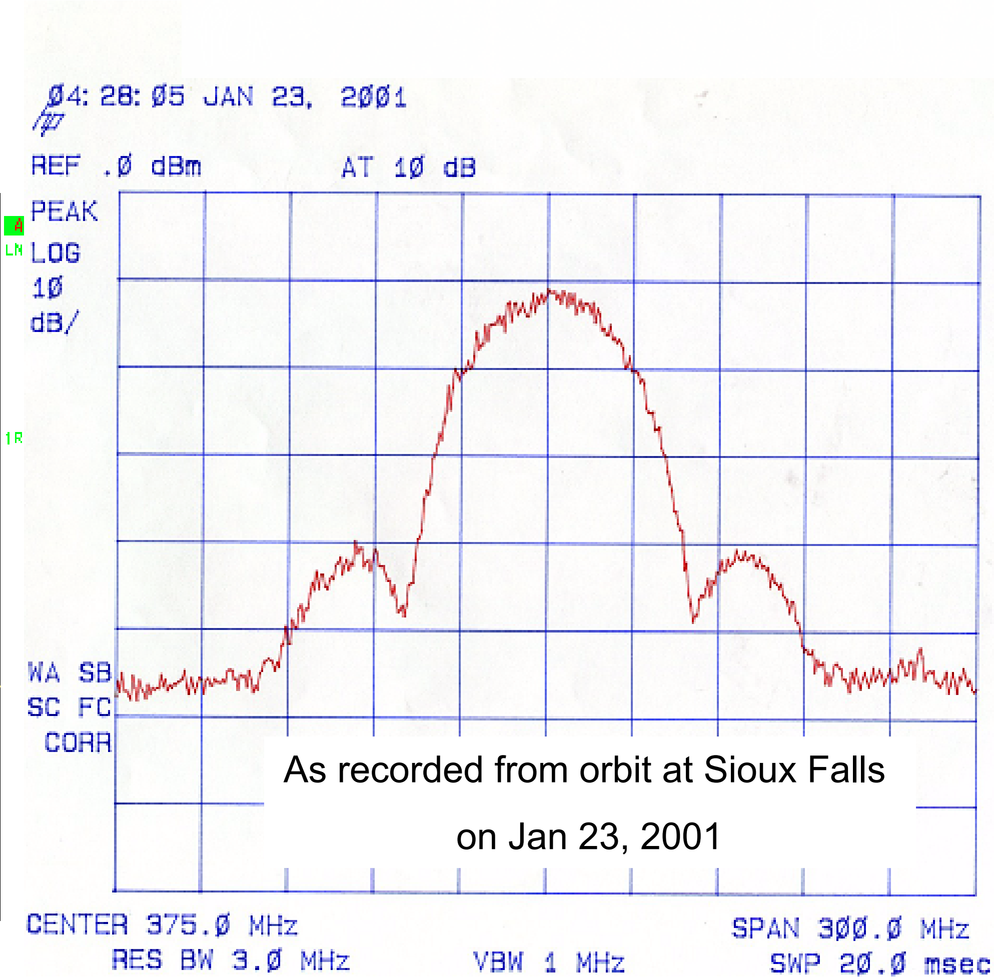

Figure 3 XPAA EIRP Radiation Pattern Performance - Frequency = 8.225 GHz, Scan Angle (theta, phi) = (0, 0), Phi = 0 - 180 Degree Plane Pattern Cut
(*) - Fails Specification Limit

# After Launch XPAA Downlink Spectrum



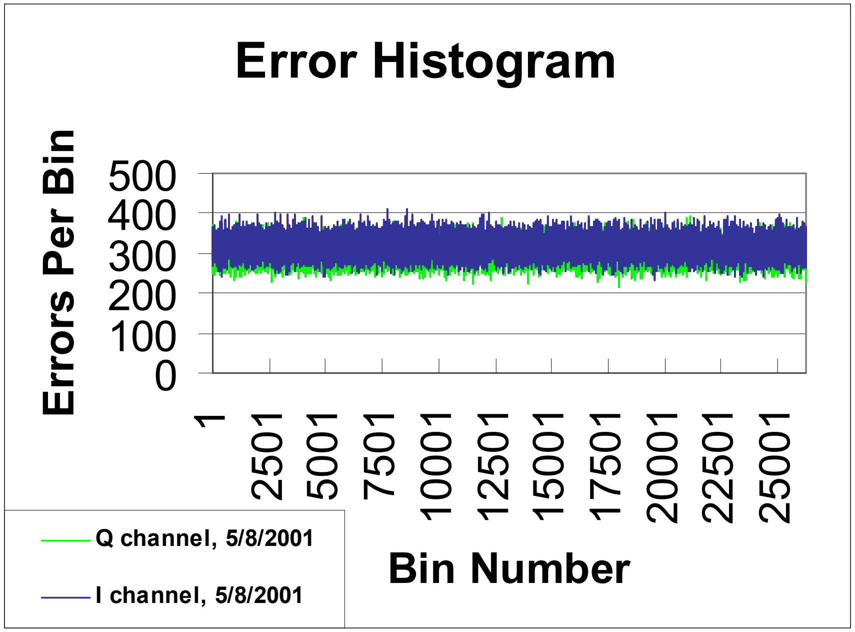



As recorded at GSFC during I&T on May 23, 2000

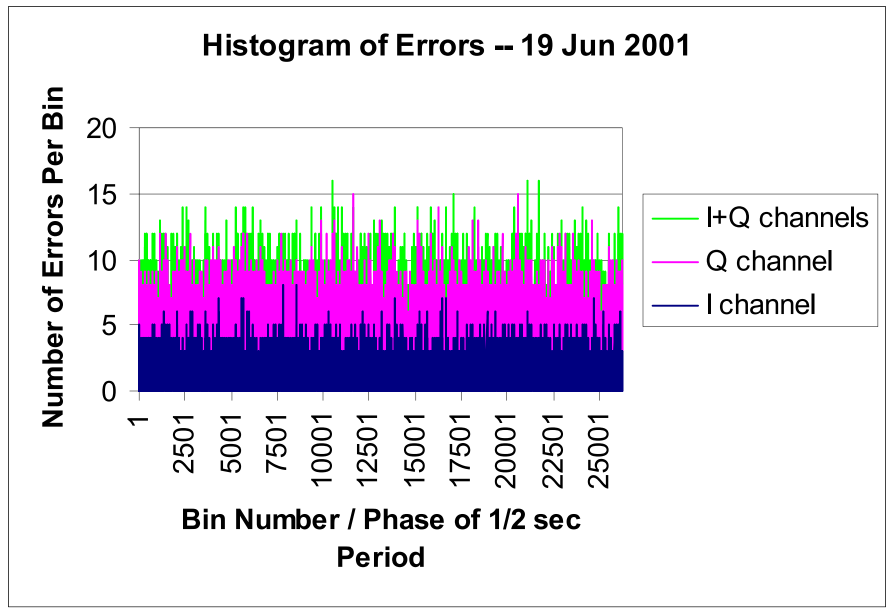



As recorded from orbit at Sioux Falls on Jan 23, 2001

# XPAA Burst Error Evaluation




- ***XPAA downlinks are generally error-free. Error evaluations are made by deliberately degrading the downlink signal-to-noise ratio.***

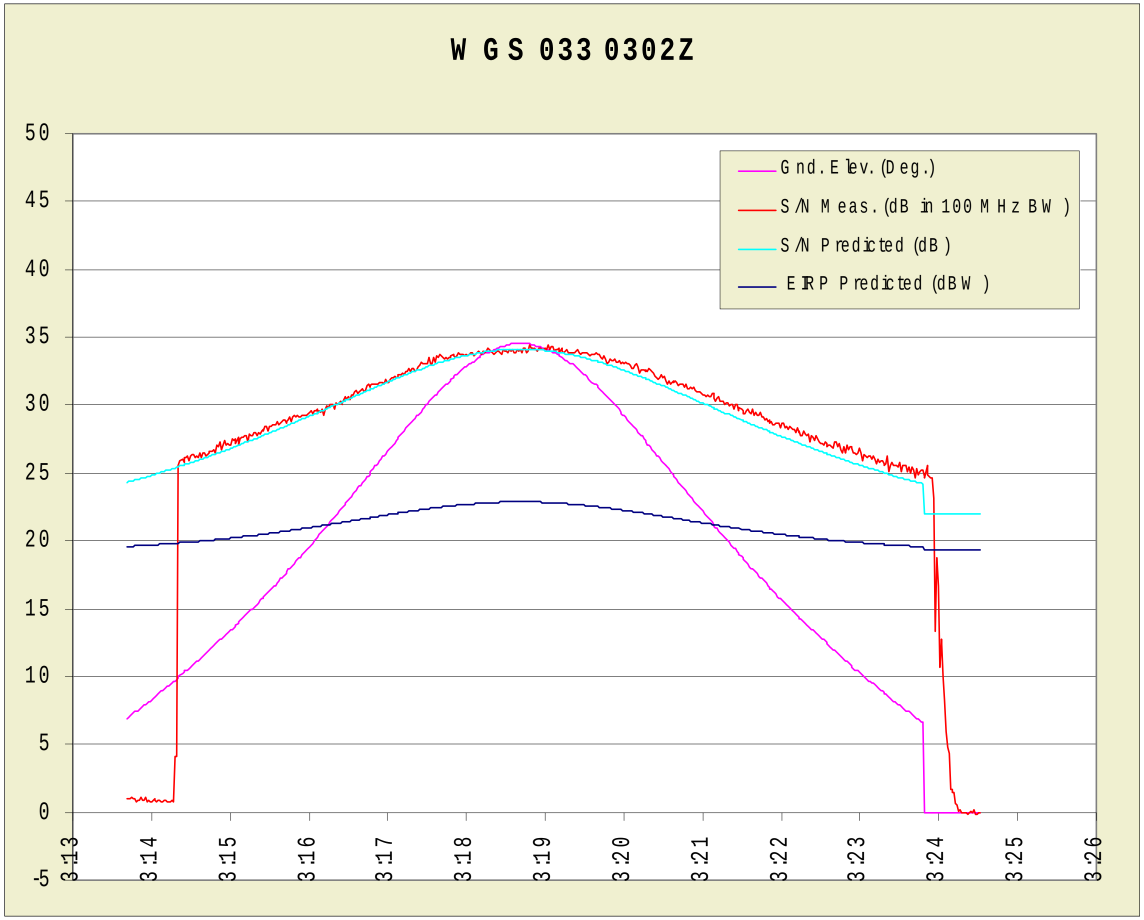



- ***No correlation yet found between electronic scanning of the antenna and downlink error performance.***

# XPAA Downlink EIRP Variation

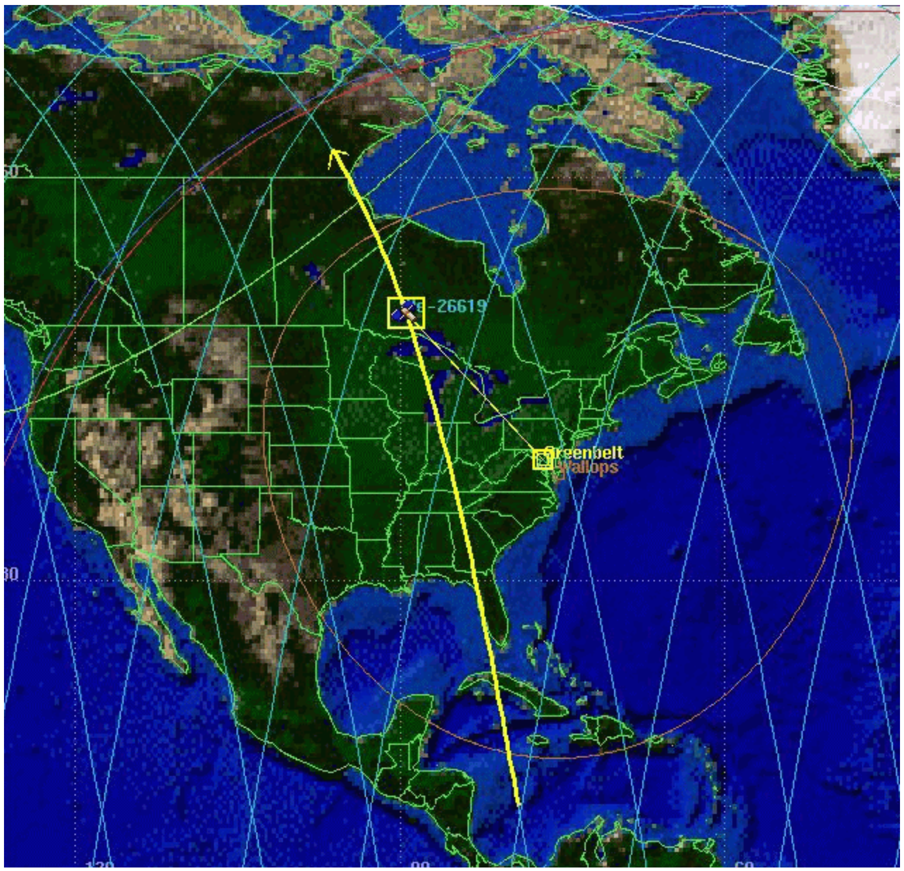


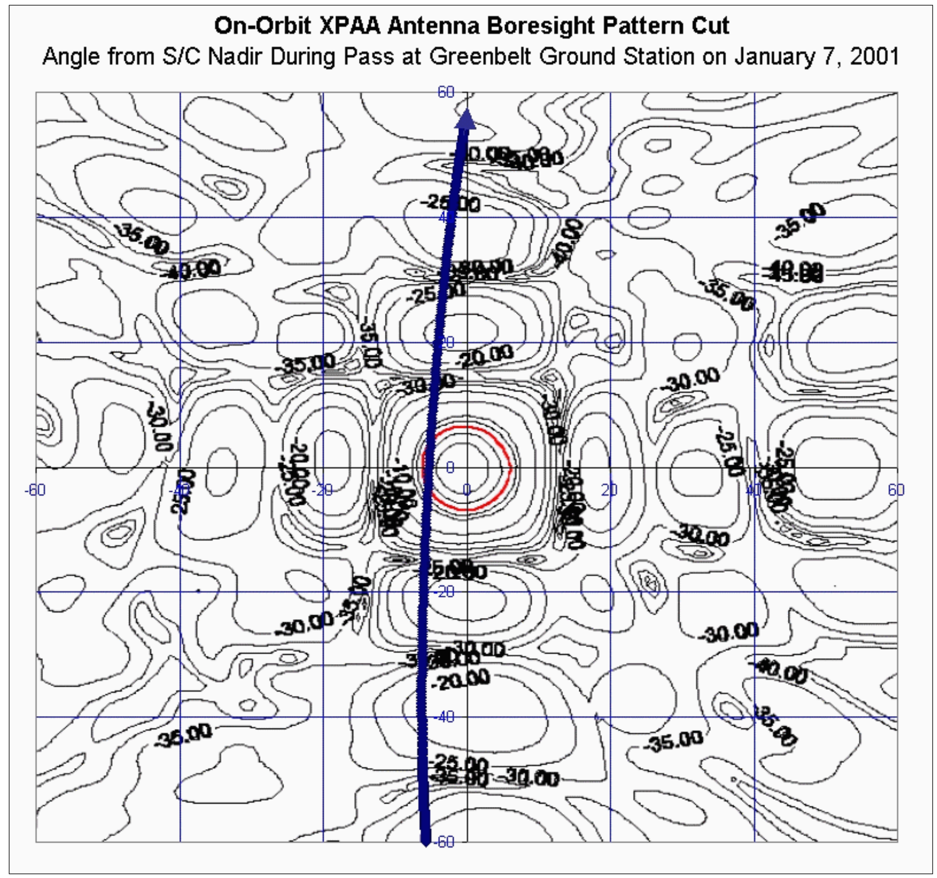
- ***The EO-1 X-band downlink power varies during a pass due to two primary effects:***
  1. ***Path losses due to range and atmosphere***
  2. ***XPAA EIRP variation with scan angle***
- ***A curve fit was made of calculated range and measured scan losses vs. ground station elevation angle***
- ***XPAA EIRP variation has been examined for 10+ passes at three ground stations (HGS, GGS, and WGS) and found to be nominal***



# XPAA Downlink Antenna Pattern

***The EO-1 XPAA antenna pattern was evaluated by fixing the beam in a nadir-pointing mode and allowing the satellite to be program tracked from GGS.***



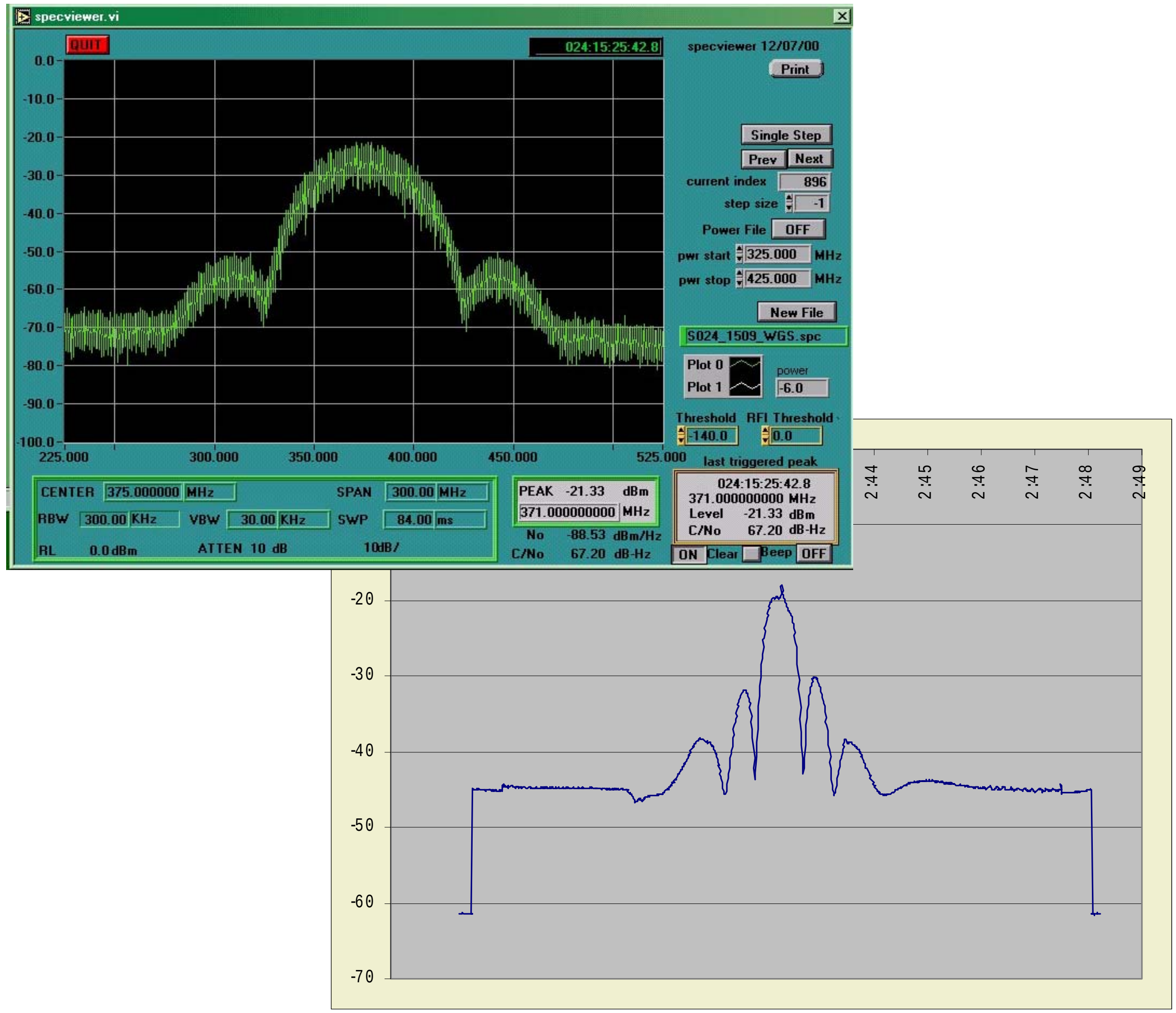



# XPAA Downlink Antenna Pattern



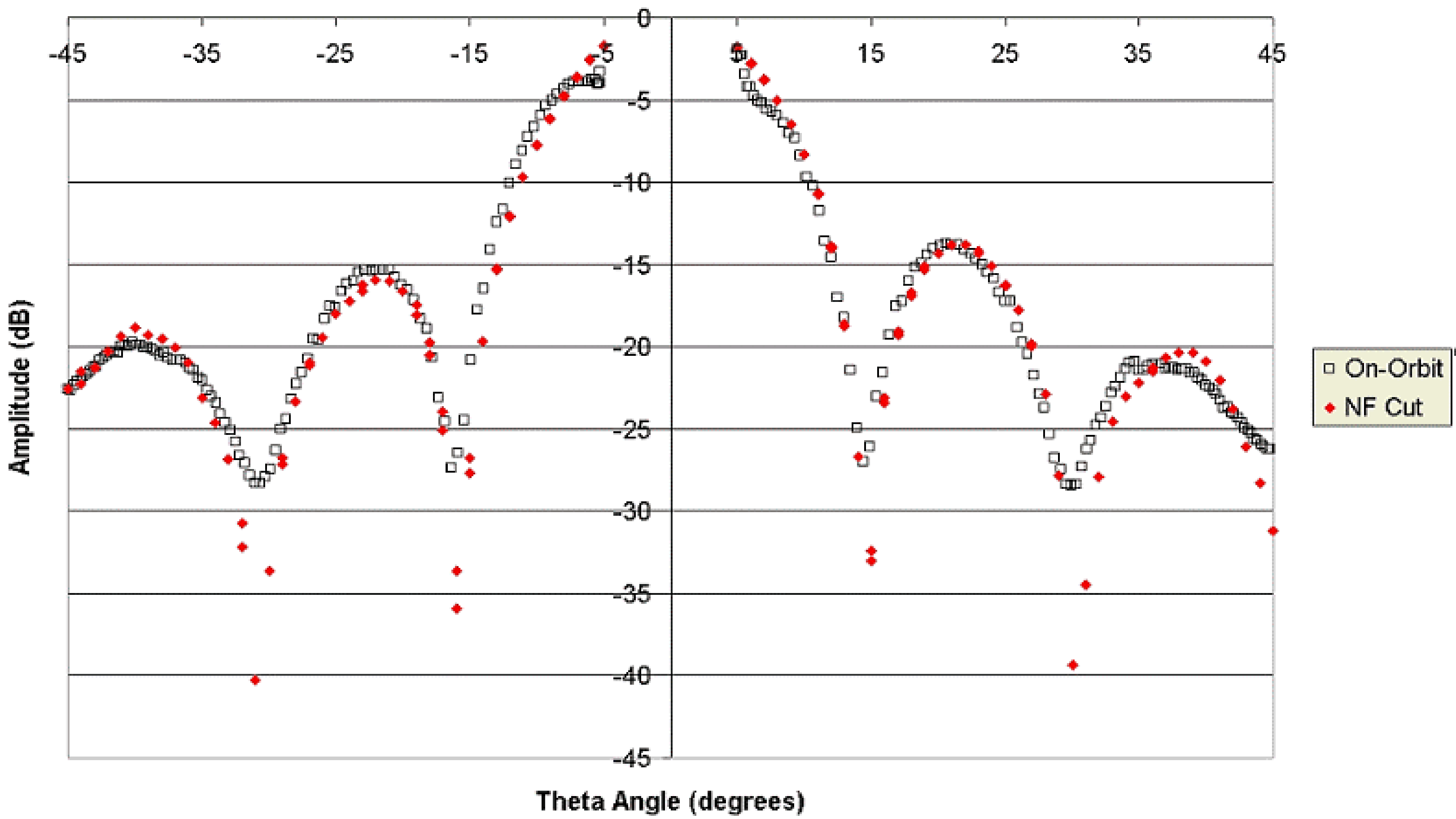
- ***The EO-1 XPAA antenna pattern was evaluated by fixing the beam in a nadir-pointing mode and allowing the satellite to be program tracked from GGS. Similar to the EIRP variation measurement, the recorded power varied due to:***

  1. ***Path losses due to range and atmosphere.***
  2. ***XPAA EIRP variation with theta angle (in this case, the antenna pattern from -64 to +64 deg. theta.***



# Pre- & Post-Launch Nadir-Pointing Antenna Patterns





# *XPAA Telemetry*



- ***The EO-1 XPAA pointing telemetry was compared to commanded angles from the ACS. The angle interpolation algorithm in the XPAA was evaluated by comparing on-board interpolated values to see that they were consistent with the ground-commanded angles.***

- ***Pointing anomalies would also tend to show up in the EIRP contour evaluation. No anomalies were seen which are attributable to the XPAA.***

- ***The EO-1 XPAA box telemetry consisting of various voltages, temperatures, and currents was compared to pre-launch data. All readings are consistent with pre-launch measurements. The antenna is typically maintained at a temperature of 25 deg. C., which rises approximately 5 deg. during a downlink event. This is consistent with pre-launch predictions.***

# Technology Transfer & Infusion Opportunities



- ***Flight of this technology was intended to be a stepping stone toward flight of phased arrays in Ka-band, enabling Gigabit data rates from EO-1 sized spacecraft.***

- ***Phased arrays in X-, Ku-, and Ka-band have been considered for a number of NASA missions including NGST, NPP, X-37, SDO, Landsat follow-on, ISS, and Space Shuttle.***

- ***EO-1 has retired much of the technology risk associated with phased arrays. Acquisition cost continues to be the major factor in final project decisions, but costs for phased arrays ARE approaching those of traditional systems as the technology matures.***

# *Lessons Learned*

- ***Near field scanning proved to be a valuable and reliable technique for trending antenna performance throughout the mission life cycle.***
- ***I&T of this technology was in general smooth and trouble-free. Some design features were identified which could further streamline those processes, such as independently switched elements and an enhanced test hood.***
- ***Compatibility tests should include all aspects of the link with the ground station, including ground antenna tracking.***
- ***A pre-planned pointing diagnostic test in software should be implemented in the phased array.***
  - ***Proving that pointing is working right once in orbit is difficult without such a test***
- ***Reliable fabrication and testing of Teflon multilayer PWBs continues to be an issue, and requires special attention.***
- ***Procurement of small quantities of space qualified components is still problematic.***

# Summary / Conclusions



- ***This technology was shown to be fully space qualifiable, and compatible with GSFC integration and test practices.***
- ***By all measures made so far, the XPAA is performing flawlessly.   All tests show a consistent performance throughout the life cycle of the antenna.***
- ***EO-1 has verified that phased arrays are reliable and compatible with the NASA ground network.***
- ***The XPAA was designed to meet a requirement of delivering 40 Gigabits per day to the ground.***
  - ***The EO-1 project is currently receiving 160+ Gigabits of data per day via the X-band system.***